Q-VALUES OF SOME NUCLIDES ON THE NEUTRON-RICH SIDE OF STABILITY

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1. Introduction

The shape of the nuclear mass surface far away from the region of beta stability is of considerable interest. It would therefore seem reasonable that all laboratories equipped with ISOL-facilities and thus capable of producing samples of the nuclides in question should put a great effort into the study of the mass surface, for instance by measuring nuclear Q-values. Those are not very easy to determine in an incontestable way, however. Any determination of the end-point energy of a beta branch gives a lower estimate of the Q-value, but in order to obtain the correct value one would have to know the energy of the level fed by the beta branch, and this is not a trivial problem. Besides, a systematic study of many Q-values is needed for constructing the mass surface, which means tedious work. Thus, experimental difficulties explain why the mass surface has not yet been properly traced in spite of the work started by various groups.

OSIRIS[1] is the ISOL-facility producing the largest variety of neutron-rich nuclides. A programme of measuring the decay energy of those nuclides has therefore been initiated. A spectrometer based on the same principle as the one described in ref. [2] but with some modifications has been built. Details of the construction are given in the following section, and results obtained are presented in Section 3.

2. Spectrometer for measuring total nuclear decay energies (Q-meter)

2.1 Basic principle

A silicon detector for beta particles is placed between two sodium iodide detectors which should have a high efficiency in summing the pulses of gamma rays cascading from a given excited level to the ground state of

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the daughter nucleus. The highest observable sum peak, presumably corresponding to the highest level with appreciable beta feed, is chosen to gate the beta particle spectrum, and the Q-value is obtained by adding the gate energy to the beta end-point energy. This technique removes the gamma effect in the beta detector, a feature of particular value for the detector arrangement to be described below, where a proper correction for the gamma effect is very difficult to carry out.

2.2 Beta detector arrangement

In the initial experiments a 5 mm thick silicon diode was used for measuring the beta particles. In order to extend the energy range this detector has now been exchanged for another one consisting of a 25 mm dia. x 5 mm thick transmission silicon detector from which a segment has been cut in such a way that beta particles from a sample will see a detector of area 12 mm x 5 mm having a sensitive depth up to 23 mm. This corresponds to the range of electrons of energy about 10 MeV.

Since the detector is rather narrow there is a large probability that a high energy electron entering the detector will be scattered out through one of the sides and therefore not deposit its /full/ energy to the detector. This will result in a highly energy-dependent response function with a large tail towards lower energies. In order to improve the situation a thin silicon detector is placed on each side of the main detector[x]. These as well as a detector for back-scattered electrons are coupled in anti-coincidence with the main detector in order to reject events with out- scattered electrons. Thus, essentially only beta particles giving off all their energy to the main detector will be registered. The response function would then ideally consist of a peak around the true electron energy with no tail towards lower energies. In practise, there will always be some tailing caused by electrons caught in the detector windows or otherwise escaping the guard system, but a substantial improvement of the response function should result, especially for high energy beta particles.

The anti-coincidence condition will cause the efficiency of the beta detector to drop with increasing energy. The efficiency function thus has

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x) The silicon diodes have been manufactured by SIMTEC Ltd, Montreal.

to be determined experimentally. This may be done by means of radioactive samples, if possible pure beta emitters, of known spectrum shape.

The beta detector arrangement is operated at about -100°C.

2.3 Gamma detector system

Two 7.5 cm dia. x 7.5 cm thick sodium iodide crystals are used as gamma detectors. Because of the smaller size these detectors are not as well suited to approximate a total absorption spectrometer as the large detectors described in ref.[2]. Therefore, the gamma detectors have been placed inside an arrangement consisting of four 20 cm x 20 cm x 40 cm plastic scintillators [x], and coupled in anti-coincidence with the summed output of these guard counters. Thus, in a case where a gamma ray or a Compton quantum escape from the sodium iodide detectors there is a high probability of a pulse in the guard system leading to rejection of the event. This emphasizes sum peaks and depresses the Compton part of the gamma spectrum, whereby the setting of gates is facilitated. In addition, the effect of background radiation originating from outside the spectrometer will be reduced.
If the high energy part of the gamma spectrum is not resolved one has to use a slice of a more or less continous gamma spectrum as gate. The beta end-point obtained will then correspond to an average of beta branches leading to the levels in the gate interval.

The ground state beta transitions can be studied by demanding anti-coincidenee between pulses in the beta detector and the pulses from both the gamma guard system and the sodium iodide detectors. Such a requirement will enhance ground state transitions in the beta spectrum registered.

A block diagram in Fig. 1 shows the electronic circuitry of the spectrometer.

2.4 Sample feeding arrangement

The spectrometer is connected to the vacuum system (collector chamber) of the OSIRIS facility at Studsvik. Samples are collected on magnetic

x) Nuclear Enterprises type NE 102 A.

tape and, after a preselected collection time, rapidly transported into a small vacuum chamber containing the beta detector system. A play-off head feeling a signal played onto the tape when in collecting position brakes the tape motion so that the sample stops in front of the detector. The stopping position is reproducible with a standard deviation of 1 - 2 mm and can be adjusted by moving the play-off head. The transport time is 2 - 3 seconds. During the measurement a new sample is collected to exchange the preceding one with the chosen frequency. It can be shown (Appendix) that this kind of intermittent measurement mode may give samples of an average strength of about 40% of the saturation rate at the collection position. The practical half-life limit for the arrangement is set by the decay loss during the transportation. If one per mill of the saturation rate is acceptable, Fig. A1 of the Appendix indicates a half-life limit of 0.4 sec.

The vacuum chamber is provided with an air-lock for the introduction of calibration samples and off-line samples.

Fig. 2 gives a view of the spectrometer.

2.5 Evaluation of the Q-value

The beta spectrum coincident with the gate is measured and registered on paper tape or magnetic tape. The spectrum resulting from accidental coincidences is also determined by changing the timing of the gate pulses.

A computer programme has been written to evaluate the end-point energy of the beta spectrum coincident with a certain gate energy with due account taken of accidental coincidences. The programme works in two steps - first using the response and efficiency functions for a conversion of the beta spectrum into the true electron energy distribution by means of an iterative procedure, and afterwards determining the end-point energy corresponding to the electron distribution by a Kurie plot using the least squares method. If desired, the programme resolves the data into two components.

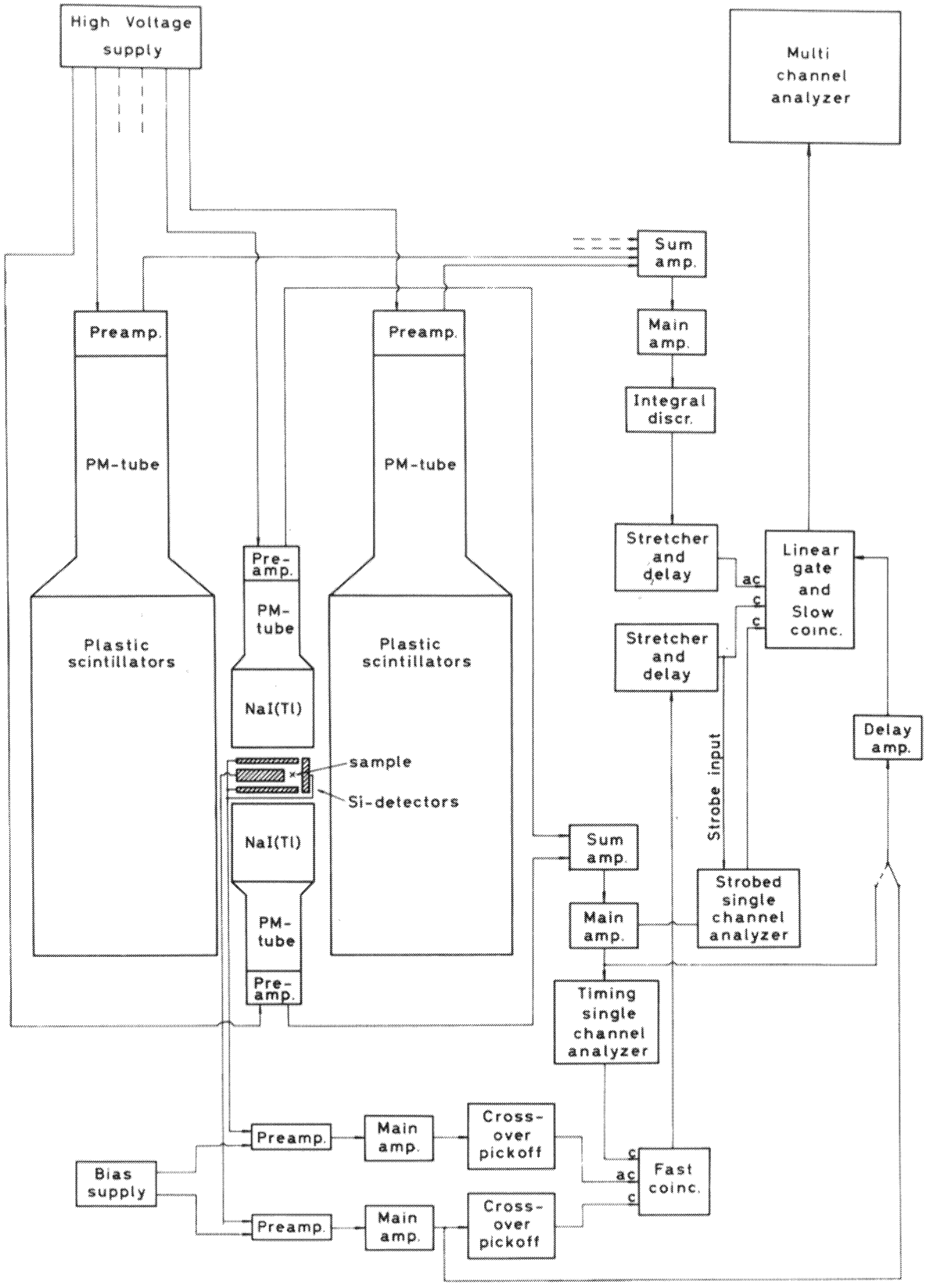

Fig. 1 Block diagram for the Q-meter

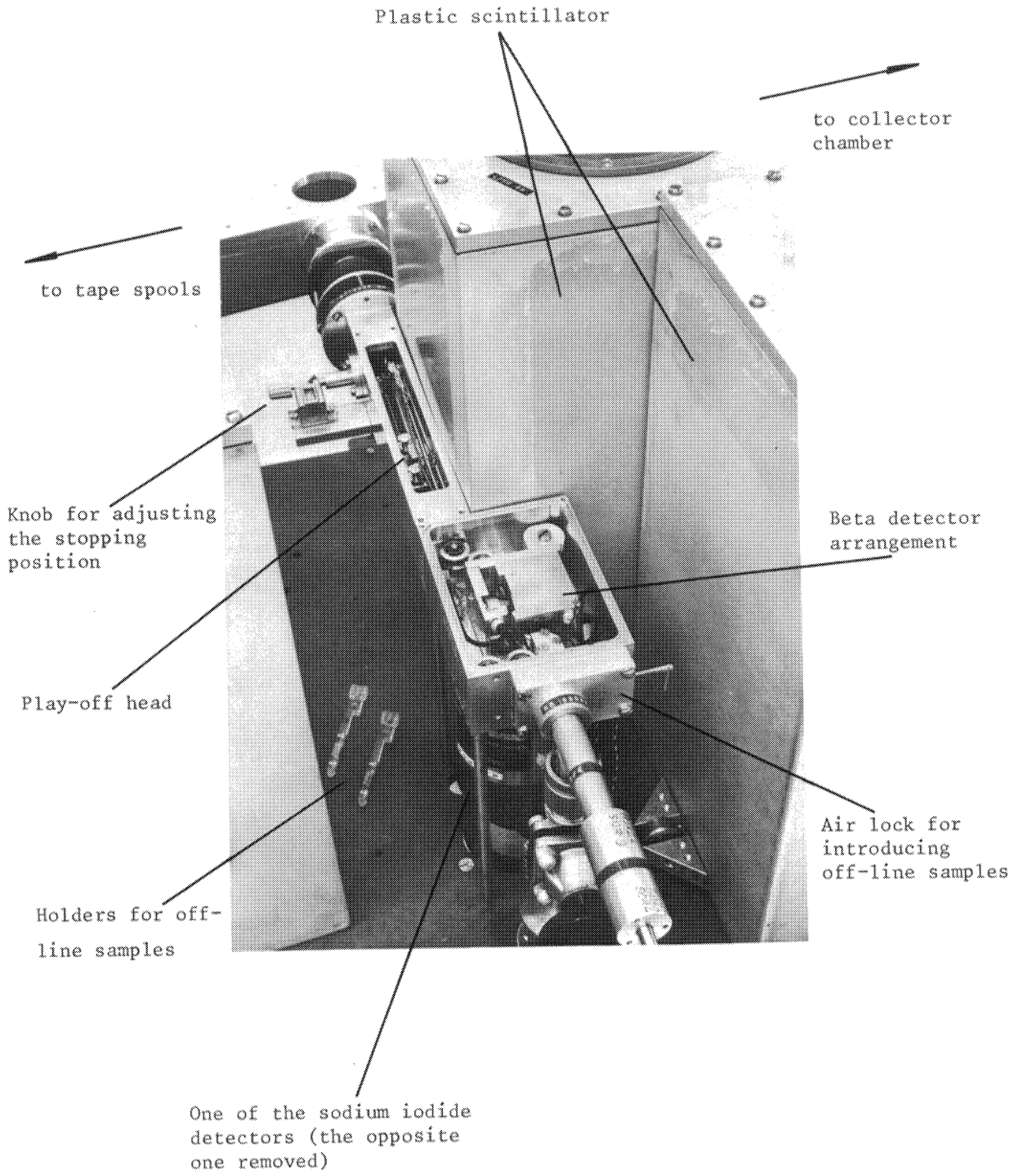

Fig. 2 View of the Q-meter

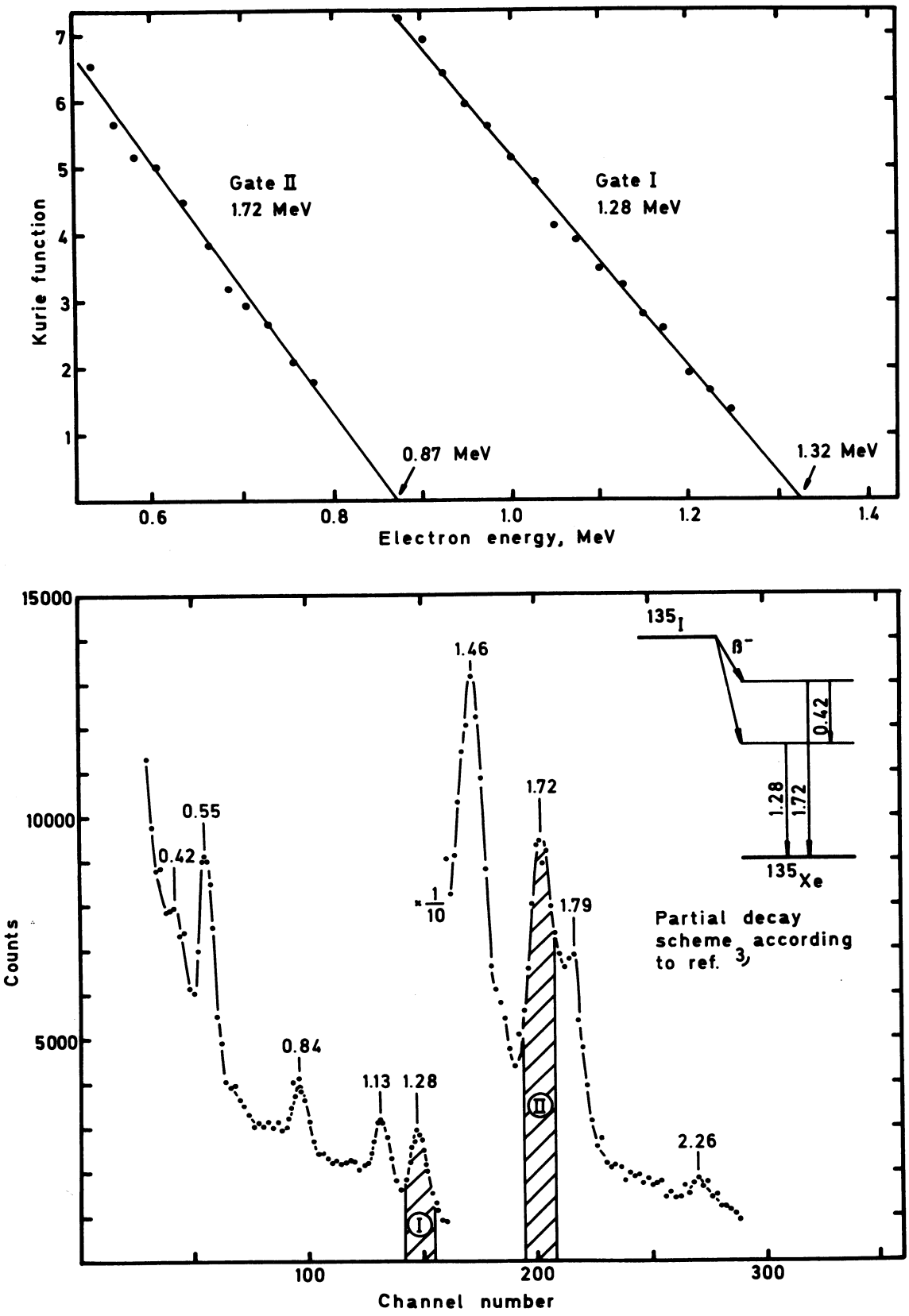

Fig. 3 Upper part: Kurie plots of beta branches of ^{135}I coincident with the gates at 1.28 MeV and 1.72 MeV.
Lower part: Gamma spectrum of ^{135}I with choice of gates indicated.

3. Experimental results

The steps in a Q-value evaluation, with ^{135}I chosen as an example, are visualized in Fig. 3. Kurie plots of beta branches coincident with gates around the gamma energies 1.28 and 1.72 MeV give the beta end-point energies 1.32 and 0.87 MeV, respectively. These gates presumably correspond to energy levels in ^{135}Xe[3], and two determinations of the Q-value, i.e. 2.60 MeV and 2.59 MeV, are obtained. Other results are presented in Table 1. The agreement with published data or estimates is acceptable. The short-lived species given in Table 1 were measured using a 5 mm thick silicon detector for the beta particles. After replacing this detector with the more powerful system described above the spectrometer has only been used for off-line samples. It is now being mounted for on-line experiments, however, and will soon be ready for measuring nuclides with half-life down to 1 - 2 seconds and beta-energy up to 8 MeV.

References

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Table 1

Experimental Q-values

Nuclide	Half-life of gamma-gate	Gamma-gate, MeV	Beta end-point energy, MeV	Q-value MeV	Average Q-value, MeV	Q-value from literature	Comment
^{90}Rb		5.188±0.001[4]	1.79±0.18	6.98±0.18	6.91±0.15	6.6[5]	
		"	1.83±0.16	7.02±0.16			
		"	1.54±0.10	6.73±0.10			
^{132}I		2.840±0.001[6]	0.84±0.08[x]	3.68±0.08	3.68±0.08	3.558±0.015[6]	
^{133}Sb	146±4 s	2.75±0.02	1.26±0.07	4.01±0.07	3.95±0.03		2.75 MeV assumed to be an energy level
		"	1.21±0.06	3.96±0.06			
		"	1.09±0.11	3.84±0.11			
	148±1 s	"	1.19±0.04	3.94±0.04			
^{133}Te		2.228±0.001[7]	0.88±0.14	3.42±0.14	3.39±0.11	3.52±0.10[7]	2.228 MeV gamma assumed to feed a 0.312 MeV energy level[7]
		"	0.81±0.17	3.35±0.17			
^{135}I		1.72±0.02	0.87±0.07[x]	2.59±0.07	2.60±0.04	2.8[5]	
		1.28±0.02	1.32±0.05[x]	2.60±0.05			
^{139}Cs		3.60±0.05	0.87±0.21	4.47±0.22	4.44±0.06	4.0[5]	
	539±20 s	2.60±0.05	1.97±0.11	4.57±0.12			
		"	1.88±0.14	4.48±0.15			
		2.18±0.05	2.23±0.10	4.41±0.11			
		"	2.17±0.08	4.35±0.09			
^{141}Ba		1.68±0.03	1.37±0.09	3.05±0.10	3.05±0.10	3.0[5]	The sample also contained a harder beta-branch, probably due to contamination. The experiment will be repeated.

x) Measured with the new beta detector arrangement described in section 2.2.

APPENDIX

Maximum sample strength at intermittent measurement

A nuclide of decay constant λ is collected for t_c seconds, transported to the detector (transport time = t_t seconds) and measured for t_c seconds while a new sample is being collected, etc. The collection rate is denoted by N nuclei/second. At saturation, this is also the decay rate at the collector.

At the end of the collection time the activity collected will be equal to

$$\frac{N}{\lambda}(1 - e^{-\lambda t_c})$$

This rate is reduced by the factor $e^{-\lambda t_t}$ during transportation, and one finds that the number of nuclei having decayed during one cycle at the measuring position will be equal to

$$\frac{N}{\lambda}(1 - e^{-\lambda t_c})^2 e^{-\lambda t_t}$$

The cycling time is (t_c+t_t) seconds, and thus the ratio between the average decay rate at the measuring position and the saturation decay rate at the collection position will be given by

$$R = \frac{(1 - e^{-\lambda t_c})^2 e^{-\lambda t_t}}{\lambda(t_c + t_t)}$$

The ratio should be optimized by a proper choice of collection time t_c. This collection time is obtained from the equation

$$e^{-\lambda t_c}\left[2\lambda(t_c+t_t) + 1\right] = 1$$

which can be solved graphically. The maximum value R_{max} of R is then found by inserting the optimum collection time into the expression above.

In Fig. 1 the ratio R_{max} has been plotted versus the half-life of the nuclide collected with the special choice of 2.7 sec. for the transport time (typical for the tape transport system at Studsvik).

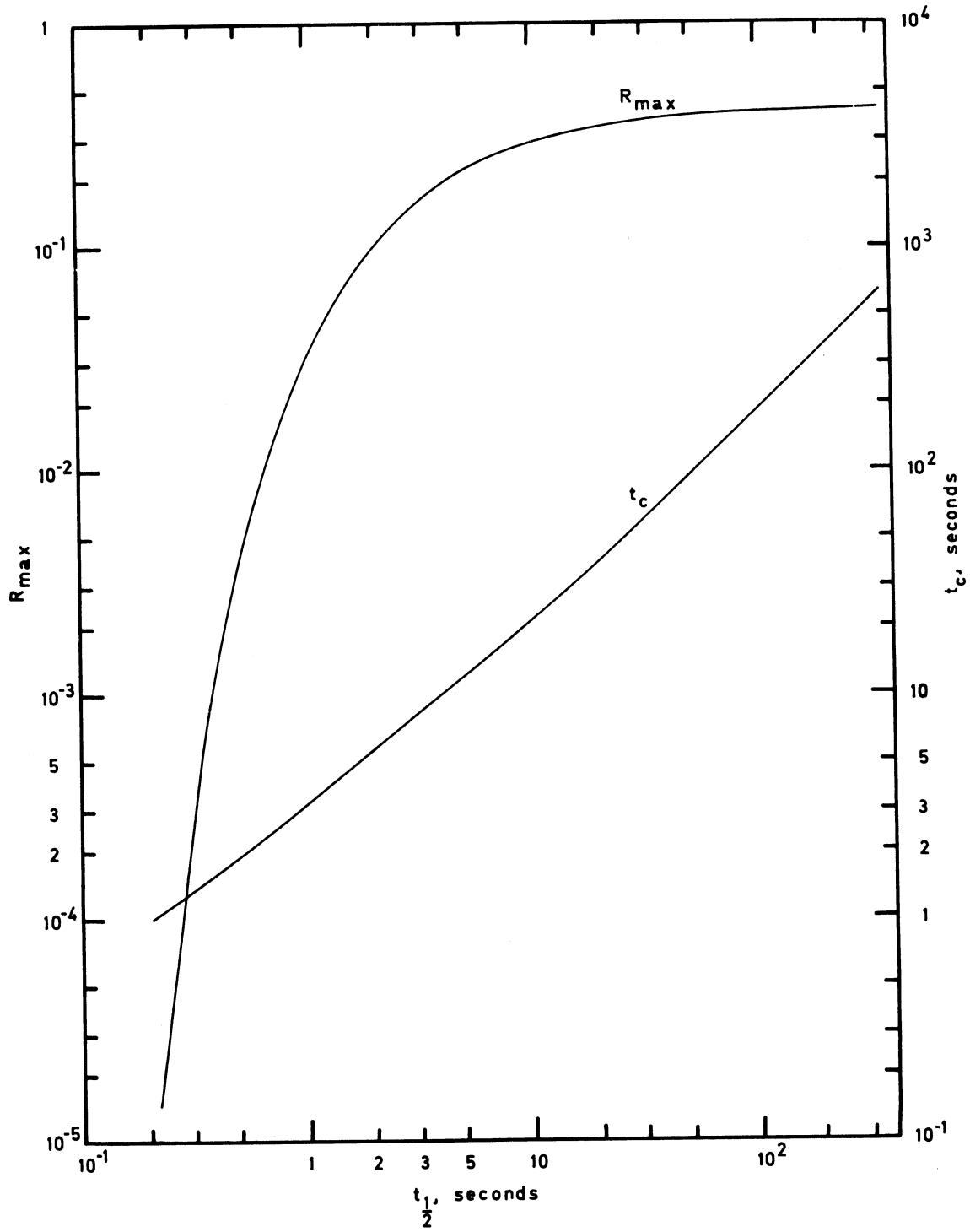

Fig. A1 R_{max} and t_c versus half-life for t_t = 2.7 s.